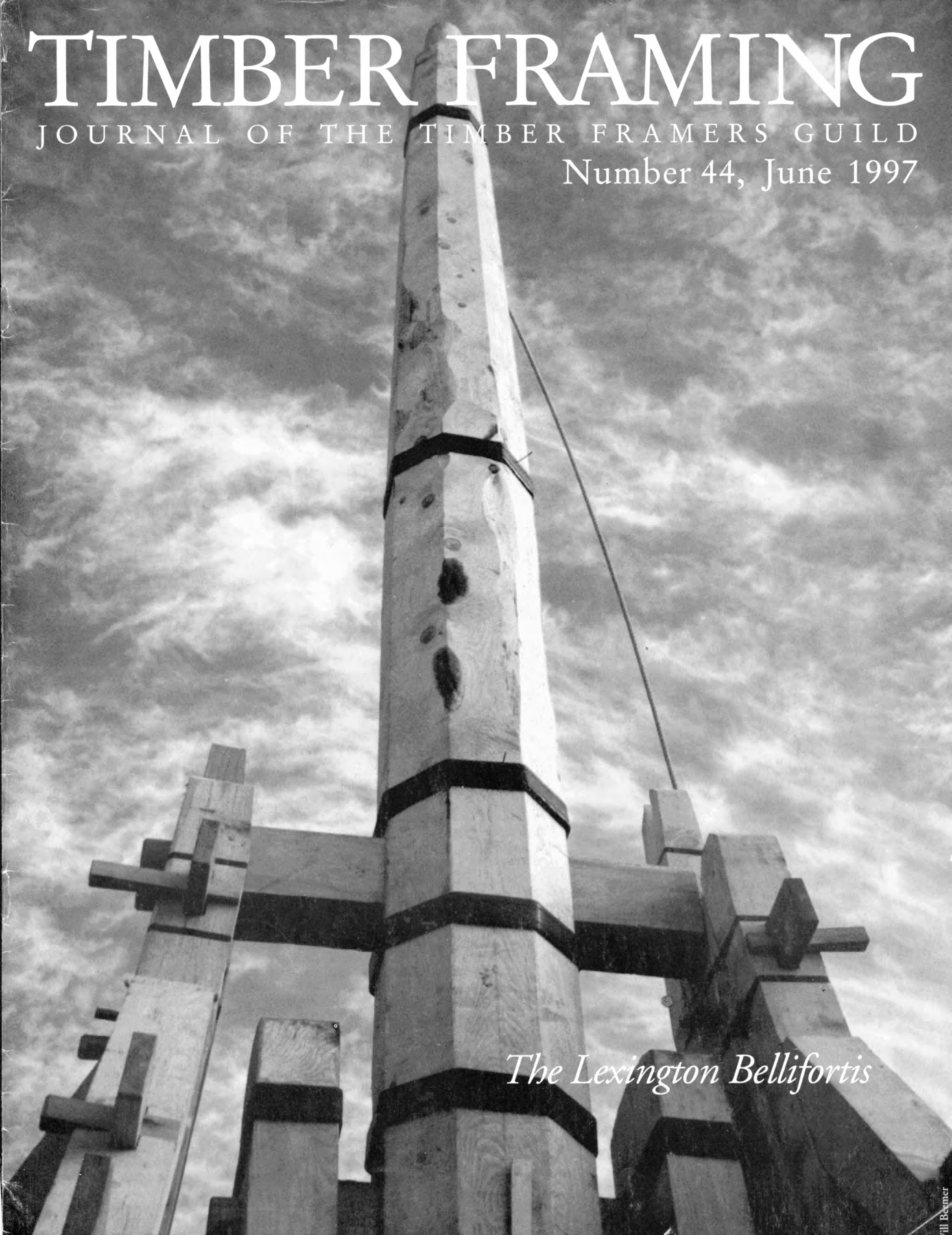
TIMBER FRAMING

JOURNAL OF THE TIMBER FRAMERS GUILD
Number 44, June 1997



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TIMBER FRAMING
INCORPORATING TIMBER FRAMERS NEWS
Number 44 June 1997

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Published Quarterly

Timber Framers Guild of North America
PO Box 1075, Bellingham, WA 98227
360-733-4001
www.tfguild.org

Editorial Correspondence
PO Box 275, Newbury, VT 05051
802-866-5684

Editor: Kenneth Rower

Contributing Editors
History: Jack Sobon
Timber Frame Design: Ed Levin

Correspondents
England: Paul Price
Japan: Michael Anderson

Subscription $20.00 Annually
Or by Membership in the Guild

ISSN 1061-9860

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TOPICS

Forest Update '97

TRY the Internet. My first stop was with The Nature Conservancy (tnc.org). Here I found addresses for the U. S. Senate and the House of Representatives (both Washington, D. C. 20501, tel. 202-224-3121).

I moved on to the Natural Resources Defense Council (nrdc.org), which has a fund of information. There are various other web sites given at this location. My particular preference is *Earth Action: The Bulletin for Environmental Activists*, which you can access directly (nrdc.org/field/acti.html). If you're a member of the National Wildlife Federation, they will send you a free news digest, *EnviroAction*, published regularly when Congress is in session. You can call 202-797-6655 for daily updates on issues, or, if you want to request the publication, 800-822-9919.

So what did I learn? Currently, the environment is not so partisan an issue as it was. The intention of the 104th Congress was malevolently clear in its willingness to abandon the environmental protection work of the last 25 years. Citizen response made a big difference and helped to thwart many ill-conceived bills that were proposed.

In the 105th Congress, the House looks less extreme but the Senate is apt to be as hostile as before. There is a lot of money behind various senators with anti-environmental agendas. At the same time, environmental groups have proven that they are well organized and can be effective again. The public has been alerted and real concern has been demonstrated. But there is no cause for complacency, and certain issues are of particular gravity for the timber framing industry and related businesses.

The March 1997 *National Geographic* magazine has an excellent article by John G. Mitchell (not the Attorney General, but the writer for *Audubon*) entitled "In the Line of Fire—Our National Forests." The foldout picture of clear-cut patches across Idaho's Targhee National Forest (next to Yellowstone Park) is a visual indictment of irresponsible logging.

In 1995, the 104th Congress passed a budget bill that included a rider providing disaster relief. This measure has come to be known as the "Clear-cut Rider." It was presented as an effort to improve the health of the national forests by removing fallen, burned or dead trees. But, observes Mitchell:

"The rider contained three key provisions that infuriated the environmental community. First, it stipulated that the salvage sales could include healthy green trees so long as they were 'associated' with the dead and dying ones. Second, it exempted these sales from citizen appeals as well as from regulatory review under such laws as the Clean Water Act and the Endangered Species Act. And third, it mandated the reopening or substitution in kind of a number of sales of living old-growth trees in the Pacific Northwest—sales that had been halted earlier to protect the nesting habitat of the northern spotted owl and the marbled murrelet, a threatened seabird. And these sales were also to be conducted without benefit of public appeal or regulatory oversight."

Although this rider is now out of date, Senator Larry Craig (Idaho) has introduced new legislation. It's still in draft form, but it went through the Senate Energy and Natural Resources Committee in December,1996. This is definitely an issue for timber framers to explore and then to voice their positions on. I have quite a bit of material on it if anyone wants me to fax it. More will be available as the legislation passes on through the process.

Another major concern is the fate of the Tongass National Forest in Alaska. This forest is the largest remaining temperate rainforest in the world and a location for old-growth timbers. In the past, Alaska's Senator Murkowski has been particularly aggressive in trying to open Tongass up for greater commercial use. Although to date there has been no new definite action, there is always talk of opening the Alaskan oil reserves or this national forest. If you felt motivated to make a statement right now, the office to contact would be Vice President Al Gore's at the Old Executive Office Building, Washington, D.C. 20501, tel. 202-450-2326.

Issues of ownership will be inherent in any forthcoming legislation on the subject of takings. A necessary fermentation will be part of the process as we all evaluate public versus private rights and the use of tax money to support our national lands under contract to private industry, or to compensate owners who feel financially mistreated by current environmental regulations.

Proper forest management of both public and private lands is an urgent need and subject to ongoing debate. Rather than Republican versus Democrat, we are perhaps falling into two new opposing camps. The first camp holds that biodiversity is the important focus. For this camp, all life is interconnected. Mankind's role may be central but should not be to the exclusion of other species. The second camp terms itself anthropocentric, putting mankind's needs before all others. Are these two camps functioning in different time zones? Which camp can best merge with Nature's timing? If the issues are moving away from our traditional parties, that seems a step of progress to me. Patience is definitely called for, but patience does not preclude positive action. —NANCY JANSSEN CURRIER

Nancy Currier (603-424-3935) is a tree steward and volunteer lobbyist for the Society for the Protection of New Hampshire Forests. She has for some time interested herself in the Guild's on-again, off-again forestry efforts.

TIMBER FRAMING, Journal of the Timber Framers Guild of North America, reports on the work of the Guild and its members, and appears quarterly, in March, June, September and December. TIMBER FRAMING is written by its readers and welcomes interesting articles by experienced and novice writers alike. Contributions are paid for upon publication at the rate of $125 per published page.

1997 Traditional Framing Symposium

IN its sixth annual public symposium, held March 7-9 at Williams Lake, Rosendale, N.Y., during a cool period in the endless winter of '97, the Guild's Traditional Timber Framing Research and Advisory Group took its customary Saturday afternoon tour. The 60 visitors and speakers visited 18th-century barns and a watermill as well as a cluster of 17th-century stone houses built by Huguenot refugees. Symposium proceedings follow. Additional speakers included preservationist Joseph Hammond ("Robert Smith, Colonial Architect of 18th-Century Steeples and Towers"); Jack Sobon ("Carpentry in the Primeval Forest," further comments on issues of sapwood and heartwood, see TF 43); Rudy Christian ("Mill Rule," a proposed category to account for modern layout of four-square timbers); and David Dauerty ("Square Rule Methodology," which will appear in the next number of TIMBER FRAMING).

MILL TIMBER FRAMING
Robert Grassi

THE extensive topic of mill timber frames covers water-powered grist and sawmills as well as windmills. Naturally, the early American colonists brought with them the technology and building styles they were most accustomed to from their homes in Europe. Regional building styles did develop, but most wind and water mills had much in common.

Early water-powered gristmills were heavily framed and double-floored to carry the weight of grain and flour products. The big difference that separated house and barn framing of the period from early mill framing was the entirely distinct timber frame, called a *husk* or *hurst* frame, built within the main frame of a mill. The hurst frame supported the millstones and the drive spindle. The reasons for the hurst frame and its various components become obvious when you understand how these early mills were operated. Millstones ranging in size from 4 to 6 ft. in diameter worked in pairs. (A single 4-ft. millstone weighed around 2,000 lbs.) Horizontally set, the bottom stone (bedstone) was stationary; the top millstone (runner) turned. A 4-ft. runner stone operated at speeds ranging from 125 to 150 rpm (the larger stones ran slower) and could produce about 1,000 lbs. of fine flour an hour.

It was imperative that the miller control the distance between the runner and the bedstone (a procedure called *tentering*) at all times during operation to achieve a satisfactory finished product. This is where the hurst frame came in. It not only had to support the weight and centrifugal force of the runner stone in operation, but also two of its components, the *brayer beam* and the *bridge tree*, which had to be adjustable for tentering. The hurst frame was separated from the main frame of the mill building so that it could always maintain the bedstone level no matter how many tons of grain or flour might be stored in the mill. Hurst frames were no longer considered necessary in mill construction when millstones fell out of favor in the early 1880s with the advent of portable gristmills.

Early water-powered sawmills were generally framed using three bents, with the central one, the *fender bent*, including the fender posts in which the sash saw slid up and down during operation. Typically, the fender bent was more heavily framed, to handle not only the extra weight of the saw but also the heavy reciprocating action of the saw at work. Though locked into both the fender beam and the fender sill, the fender posts were removable. With the advent of the circular-saw mill toward the latter part of the 19th century, sawmills no longer needed special framing members incorporated into the building. Circular-saw mills came with their own portable frames. To confuse matters, the framework of a circular-saw mill that carried the saw mandrel, the blade and pulleys was referred to as a husk or hurst.

Colonial Williamsburg

The post mill at Williamsburg, a rare form of windmill, of which only reproductions exist in America. Below, a restored stone-built French smock mill. Only the cap turns.

Ken Rower

Timber-framed windmills generally were of two basic types. The earliest mill brought over from Europe was the *post mill.* The main body and frame of the mill were supported and could revolve 360 degrees on one massive post, hence the name. The post was supported by cross-trees and held plumb and braced by quarter bars. The crown tree was the large beam resting on the post top and carried the rest of the body framing. It's quite amazing how meticulously these mills were constructed and made to balance on their posts. They could operate in a light breeze and still hold up to head-on gale-force winds without falling apart. No examples of colonial post mills are known to have survived in this country, but we do have three fine reconstructed working examples, one (shown at top) at Colonial Williamsburg.

The second type of windmill, the *smock mill,* was developed in Europe and appeared in North America by the mid-18th century.

In this mill, only the cap could be turned into the wind, the body containing all the machinery remaining stationary. Typically these mills were eight sided, but not always. The eight posts were called cants. Post and smock mills did not contain separate hurst frames like their water-powered brethren, but they did contain similar components like the brayer, bridge tree and stone beams. These mills had very limited storage capacity, and therefore millers did not have to be as concerned about the level of the bedstone easily getting out of truth. The transverse floor framing found in North American smock mills was reputed to have been developed here and not in Europe. Many of these mills were moved to new locations during their lifetimes. We have quite a few examples of smock mills that have survived on Cape Cod and Nantucket Island in Massachusetts, on the coast of Rhode Island and, with the largest collection, the northern shore of Long Island, New York.

SOUTH BERWICK, MAINE, CHURCHES

Arron Sturgis

MAINE author Sarah Orne Jewett describes with passion her First Parish Federated Church in South Berwick, the town where she lived and wrote. What's curious is that this church and the First Baptist Church, not a stone's throw away, are identical in size, architectural embellishment and, yes, in framing as well. At the roof, exquisite scissors trusses arrayed 30 in. on center span 50 ft. The beauty and strength of the trusses are apparent in the pine and spruce timbers and the hand-wrought hardware. Each stick is hewn on one side and sawn up and down on the opposite, implying that the trees were hewn in the woods and brought to the mill for division.

Significant changes over time have also followed parallel paths in the two churches. After both were built in 1825-6, in the middle of the century both were raised up to allow new foundations and vestries to be placed beneath them, and both had facelifts in which the original Ionic columns and multiple doors were changed to pedimented openings over a single door.

The Baptist Church framing remains more nearly intact, however, for in 1888 the Federated Church was altered to accommodate a new choir loft, in the process losing bearing walls and leaving the belfry framing sitting atop a 7x7 tie beam with a clear span of 28 ft. between posts. Fortunately for the Federated Church, the scissors trusses picked up the load and held the belfry frame in place—for a while.

Fixing this structural error was much like threading a needle. Through a 1-ft.-square opening in the side wall, we drew in a 26-ft. 8x10 red oak beam and winkled it into the 14-in. space between the existing tie beam and the choir loft ceiling. The new span was reduced to 18 ft. and the support beam was in effect substantially deepened. That both churches were built in the same fashion suggests one builder. But why would congregations of different persuasions build identical churches within sight of one another?

EXTINCT FRAMING: RAILROAD BRIDGE TRUSSES

Jan Lewandoski

I HAVE often contended that the greatest timber frames, in terms of both design and scale, are probably no longer with us. We have but a small fraction of the medieval European body of work, and yet what we have is astonishing and grand. The great long-span (150 to 250 ft.) wooden railroad bridges of the 19th century are all gone, as are all but a few of the even longer spans (up to 360 ft. in the clear) designed for lighter vehicles. The era of giant wooden naval vessels, "built to be lost," is also long gone.

Another kind of of timber work, unparalleled in the loads it was asked to carry, was built to be ephemeral. I refer to the centering used to support the entire weight of stone arches until they were joined at the center. In this same category were the timber towers used to suspend the 502-ft. steel arch spans of the Eads Bridge across the Mississippi in 1874, until they could be joined at their centers. The corner posts of these towers were composed of gangs of four 12x12 yellow pine timbers joined into one with shear blocks and bolts.

I continually research extinct frame types, both by examining ruins and through documentary evidence. Recently I purchased an antique book, *Ensamples of Railway Making*, published in London in 1843 and directed to the attention of "The Civil Engineer and the British and Irish Public." One portion of the book was devoted to the railways of Belgium, but the greater part, amounting to almost 80 pages and 17 superbly drawn, foldout plates (unfortunately difficult to reproduce here), discussed wooden bridges on the Syracuse and Utica Railroad, as built in 1837. It is rare to have this level of documentation for timber bridges of this age, and the plates show us that their like have not survived. Following are examples of what the timber frame historian can discover.

These bridges (at least 22 not including trestles), with spans from 30 to 100 ft., were uncovered, although the trusses themselves were coped and boarded. Many of the bridges were double barrelled, i.e. had three trusses. The timber of choice was white pine with white oak trenails. The exception was for piles driven into the ground, which were recommended to be of white, yellow or pitch pine, white elm, cedar, black ash, tamarack or hemlock. The trusses were framed of plank, 4x15, 4x12, 3x12 by as long as 66 ft., but in no way resembled the Town plank lattice truss that was already common. Rather, the trusses can be described as queenpost trusses with other queenpost and kingpost trusses within them, containing counter braces as well, and sometimes clasped by plank arches that spring independently from the abutment.

As the trusses approach 100 ft., they become increasingly complicated and are held together with 2-in. trenails, 1-in. bolts and iron splice bars bolted across the tension joints in the bottom chords. Finally, in the timber-rich environment of upstate New York at the time, these trusses sat upon wooden trestles for abutments and piers, and even where the trestles sat upon stonework, that stonework in turn sat upon mats of timber laid deep in the water table. All of these points are illustrated and specified in this fascinating book.

This work also contains a lengthy argument as to why Britain and Ireland should cease building stone or earthen railway viaducts and convert to wooden trusses and trestles. The point is to free up capital, and according to statistics supplied, wooden bridges cost about one-fifth as much as equivalent stone spans. The fact that uncovered wooden spans might last only 20 years as opposed to the very long life a stone bridge might have was addressed directly: the capital saved due to lower initial cost, if invested well, could easily pay to replace these bridges repeatedly, with cash left over. This is the opposite of the argument made in favor of covered wooden spans today, namely that they may cost more but they easily outlast concrete or even steel bridges.

While some publications on framing romanticize 19th-century America as a kinder, gentler era, it can alternatively be seen as scientifically and economically progressive and aggressive. Here are three ideas from the *Ensamples* book: "Twenty years at a given cost is better than forever at double the cost." "Why should public works last forever?" "Extensive utility, economical execution, immediate returns—these are the great desiderata of American engineering." In describing these American bridges, the anonymous author states "a rigid regard to utility alone has been observed. . . . all useless details and local variations are suppressed." Ironically, such trusses remained local in application and rather idiosyncratic in detail.

OLD WAYS OF MEASURING

Rudy Christian

THE architect, builder or historian who is asked to document a timber frame structure often finds that the task of drawing the framework is quite complex, and sources of information how to proceed are for the most part nonexistent. This problem is compounded by the many variations in frame typologies, timber sizes, conversion techniques and layout methods. Further, most timber frame buildings have been modified or repaired over their lifetime. All too often, the solution to this documentation dilemma is to apply contemporary methods of measuring and drawing, or to "invent" a method in hopes of recording the important information hidden in the frame.

Mathematical Modeling. A good first step in learning to survey timber structures is to decipher the pattern or mathematical model the builder used as reference. S .E. Todd stated in his 1870 work, *Todd's Country Homes and How to Save Money,* "The builder, while laying out a frame, needs to set up a regular 'air castle' before his imagination, so that he can perceive how every piece of timber, when he is laying it out, or framing it, will appear after the structure is raised and every part is in its proper place." This air castle can be interpreted as a structure made of playing cards. Each card within the structure can be thought of as a plane or two-dimensional surface. These surfaces represent the planes of reference used to locate all of the timbers in the frame. The intersections of these planes of reference form lines, each referred to as an "arris," which establish a wire model of the structure itself.

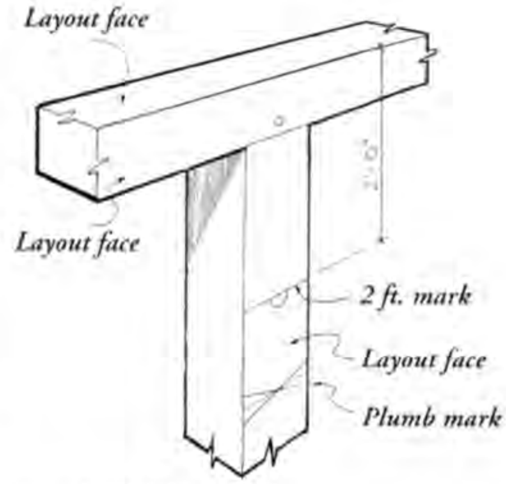
By establishing the planes of reference and the intersections of those planes, the critical or "layout" dimensions of a frame become obvious. Part of this understanding comes from the practical knowledge of the way this layout work was done. In early timber framing, timbers were worked by scribing each intersection or joint in a setting where large sections of the frame could be assembled and fitted up. The dimensions of the frame were established by taking accurate measurements and blocking up the timbers to represent a level plane. Richard Harris refers to this plane as the "upper face" in his 1978 book, *Discovering Timber-Framed Buildings,* because it was the face of the crossframe or "bent" that was up during scribing. In the erected frame this face would actually be one side of the bent.

Hewing with an axe was the timber conversion method for early timber frames. Although this process could be done in a way that produced remarkably smooth timbers, in most cases the timbers were only hewn to a surface workable for the framer. Variations in size and shape were accounted for in the scribing process. It therefore becomes necessary in surveying such a frame to establish where the framer was taking measurements from or to. In the case of a bent, the width is measured from the outside of one exterior post to the outside of the opposite exterior post. Likewise, the length of the frame can be found by measuring from the outside face of one corner post to the outside face of another on the opposite end.

But recording the correct locations for the interior bents or posts in a frame requires understanding the concept and use of the upper or "layout" face. Since during the process of scribing the joinery the framer blocked up the timbers to establish a level plane, the layout face of a bent can usually be determined by which face of the bent the timbers are flush to. (Braces typically tell the story since they are much smaller than the posts and connecting ties, so the offset is obvious.) The side of the bent to which the timbers are flush is then the side to which field measurements are taken. Often "marriage marks" will indicate the upper face. In many cases the orientation of these faces within a frame can be predicted. The English and German barn framers, for instance, almost always oriented the interior layout faces toward the threshing floor in the central "bay." The Dutch, however, were more likely to orient all bents toward the same end of the frame excepting the last in a series, which would naturally face out.

It is important not to assume field measurements can be taken at convenient locations within a frame. A great deal of movement normally occurs during the life of a framed building. Since timber frames were constructed of green timber almost exclusively, the shrinkage, twisting and bowing during drying often caused significant deviation from the original layout. Since most early foundations tended to move over time, the locations of framing members may have also changed. These factors, combined with changes, repairs and additions, make it imperative for the surveyor to investigate carefully before taking measurements.

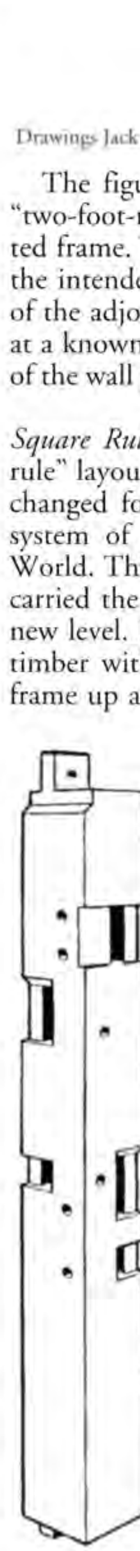
Accurate measurements can often be taken in areas of the frame least likely to have moved over time. Measuring a frame at or near floor level is the most likely to produce errors. The locations of bents can better be measured at the wall plates or roof purlins. Since the change in length of timber when it shrinks is small, the record taken at the plate can be reasonably accurate. The width of the frame can be measured at the location of the principal tie beam in each bent. Care must be taken in this measurement since withdrawal or failure at the joint of post and tie can be significant, and shrinkage in the cross-section of the posts must be accounted for. The height of the frame, in most cases, is measured from the top of the sill to the top of the wall plate. One exception is when posts rest directly on stone or masonry piers, which cause them to rot and "recede" from their original height.



Drawings Jack A. Sobon

The figure above shows the use of the "two-foot-mark" in laying out a scribe fitted frame. The mark was placed 2 ft. from the intended location of the reference face of the adjoining timber. Since this mark is at a known location, the intended location of the wall plate or sill may be extrapolated.

Square Rule Layout. Although the "scribe rule" layout system remained relatively unchanged for centuries in Europe, another system of layout developed in the New World. This system of "square rule" layout carried the concept of the "air castle" to a new level. By imagining a perfectly square timber within each actual timber used to frame up a building, it became possible to lay out and cut an entire frame without having to work at full scale. Each timber could be worked individually, and none needed to be pre-fitted before the frame was raised. This was accomplished with the use of "gains" and "housings" (at left), which are a great aid in measuring and documenting frames. Since the intention of the joiner was to create perfectly sized timber at each joint location, the wood remaining leaves a very accurate record of the mathematical model the joiner had created.



The alignment of joinery to a layout face is still common in this newer system. In many frames the record of the layout still exists in chalk. The framer would determine the working dimension of the piece to be cut and a working line would be "snapped" along the timber to locate the base of the housings. This transposed line was often 1 in. or ½ in. under the "nominal" timber size, or in some cases the true size, if the hewing was all done oversized. By measuring the shoulder-to-shoulder length of a tie beam, and adding the net dimensions of the posts on each end, the layout dimension can be determined. Housings, along the plate for instance, also greatly simplify the task of measuring bent locations. Since housings are less likely to have become obscured than the scribed marks on a frame, accurate measurements are more easily taken.

The reductions made to tenoned timbers are also of assistance in surveying and recording. Adzed reductions, sometimes known as gains, are typically done on the side of the timber opposite the reference face. This can provide valuable information, particularly in the case of interior posts. In some cases, however, a gain may exist on both sides of a tenon. Then it may become necessary to look for other clues. Braces entering a post on opposite sides can often provide the information needed. The brace cut into the layout face will normally be unhoused.

The Joiners' Language. A further understanding of how the framer saw the frame comes from learning the "language" the framer used to lay out the joinery. Many historians believe the framing square and mortise and tenon layout developed hand in hand. In most cases, the location and size of mortises and tenons are a direct reflection of the widths of the legs of the framing square, i.e, 1½ in. and 2 in. The most common language would appear to be 2-2. This indicates a 2-in. thick mortise or tenon, offset 2 in. from the layout face. With hardwood or the smaller softwood scantlings, a 1½-1½ layout (sometimes humorously called *schmaf-schnaf*) may be used, and massive principal tie beams can be found with 2-3 or bigger layouts.

Understanding this language provides another documentation tool, since it serves to confirm which face of a timber was used for reference. It's also important in developing working drawings for restoration and repair work. Particularly in the case of square-ruled frames, the recording of the layout language assists in fabricating replacement timbers, which in many cases are interchangeable throughout the frame.

Another part of joiners' language is found in standardized measurements. This may be in part due to the lack of good paper documentation. It's unlikely most frame carpenters had a set of drawings on their dashboard until well into the 19th or 20th century. Instead, certain dimensions were standard for working out a frame. Braces, for instance, seem to have become standard shortly after the introduction of the square rule layout system. In barns throughout the Midwest, braces are laid out wih 36-in. legs nearly everywhere in the frame. In some cases they are pushed to 48. This layout refers to the distance measured from the housing along the connecting tie or plate, or down the post measured from the housing.

Timber section is also usually standardized. In English and Germanic framing, even-numbered square sections are common although far from invariable. In larger barns, 4x4 scantlings serve as braces and siding girts, while scaffold ties, purlin posts, purlins and intermediate posts may be 8x8, and principal tie beams and main bent posts are commonly 10x10. Dutch barns provide exceptions to this rule, often with rectangular timber. Although standardization is more frequent in industrial and square-rule framing, it can serve to help establish the logic of the frame itself.

Hay mows and threshing floor widths seem most often to be measured out in even feet, rather than feet and inches. This would seem reasonable in that remembering, rather than ciphering, would greatly aid in being able to cut a frame quickly. Even the distance from the sill plate to the top of the wall plate is most often in even feet. Of some interest is the fact that the dimension 14 ft. appears quite often. The reason for this is obscure, but one of my favorite stories has to do with the height a man trimming trees for wickets or waddle can reach with a single section of ladder carried into the woods. This might explain the availability of good logs about 14 ft. long. Then again, maybe not.

To summarize, we can begin to establish a simple regimen for recording timber frame structures:

Determine the type of layout system used in framing up the building.

Determine the layout faces of the respective components.

Determine which parts of the frame have been added or modified.

Determine the working dimensions of the timbers.

Determine the language of the joinery.

Measure the frame where the information is intact.

Record the information as the framer would have done. —RUDY R. CHRISTIAN

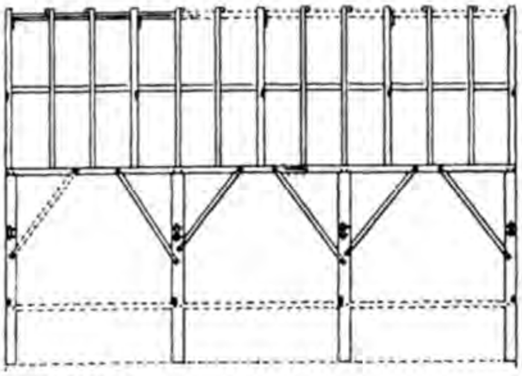
DUTCH-AMERICAN TIMBER FRAMING

John R. Stevens

THE Dutch established their colony on the Hudson River in 1625, first building a fort on the tip of Manhattan Island, where Battery Park is today. This became the nucleus of the town, New Amsterdam, renamed New York after its capture by the British in 1664. The sponsor of the New Netherlands colony, the (Dutch) West India Company, was primarily interested in trade with the Indians for beaver skins and had only slight interest in the settlement of the colony. The Dutch population meanwhile had little incentive to emigrate to the New World. The Netherlands at that time had a high level of prosperity and the highest standard of living in Europe.

Gradually, settlers did come to the New Netherlands. Some were Dutch but many were from other European countries: French-speaking Protestant Walloons from the Spanish Netherlands (Belgium), Danes, Norwegians, Germans. As best we can judge from their few extant buildings surviving from the 17th century, the architectural and structural idioms they adopted were somewhat simplified versions of the styles used in the Netherlands. An early view of New Amsterdam, the "Prototype View" of ca. 1650, shows mostly timber-framed houses clustered around the fort. These houses resemble those still standing in the Zaansee region north of Amsterdam and built about the same time. A slightly later and remarkably detailed depiction—the "Castello View" (ca. 1660)—shows orderly streets lined with brick-fronted houses. While some of these houses may have been of solid masonry construction, many were timber framed with brick fronts fastened on with iron anchors. A few surviving pictures show these anchors sometimes fashioned as numbers, thus dating the building. Similar houses can be found today in towns across the Netherlands.

Forty-two drawings of building construction (houses, barns and mills, the majority of the construction illustrations for my book-in-preparation, *Dutch-American Building*), reveal that the common denominator of Dutch-American timber framing was the use of a series of more-or-less equally spaced transverse assemblies or bents. Each comprised two posts and an anchor (tie) beam connecting them by through-mortise-and-tenon connections. In barns especially, the tenons projected through the posts a foot or more and were often outside-wedged as well as cross-pinned. Through-mortised construction is also visible in houses built before the end of the 18th century, in which second-floor beams and wall posts were exposed. The Dutch bent system persisted well into the 19th century although in houses it was concealed behind plaster. The Benjamin House of 1829, formerly at Northville on the north shore of Long Island, and now removed to Old Bethpage Village, is a fairly late example and in an area where one would not have suspected Dutch structural influence.



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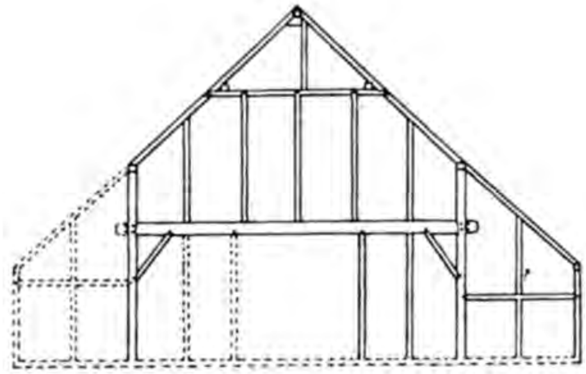
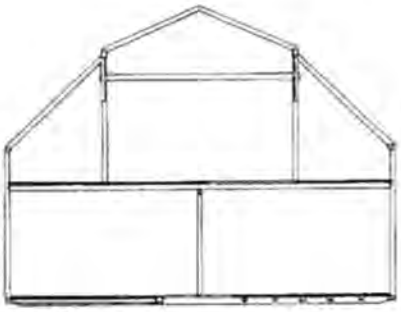
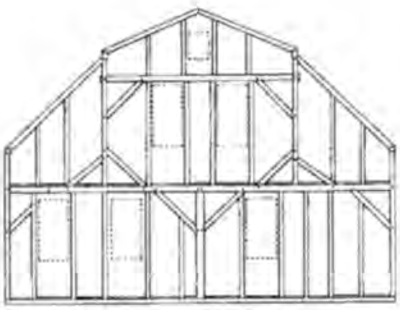


West elevation

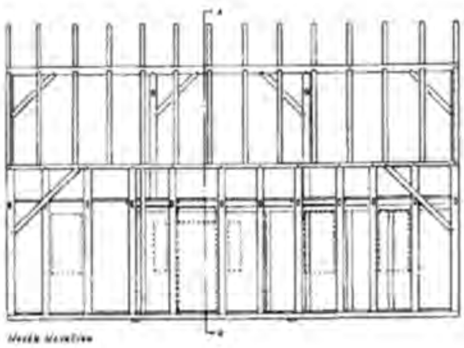
Above, views of the Garret Niewkirk barn, 1766, West Hurley, Ulster County, New York. One of the earliest of the surviving Dutch-American barns, it is exceptional in being dated and in having a roof frame of common (pole) rafters supported on purlins, the latter in turn supported by collar beams at the principal rafter pairs and the whole topped by a ridge-piece, rarely encountered in Dutch-American barns. One side-aisle and the original floor structure are missing.



Section A-A



East elevation

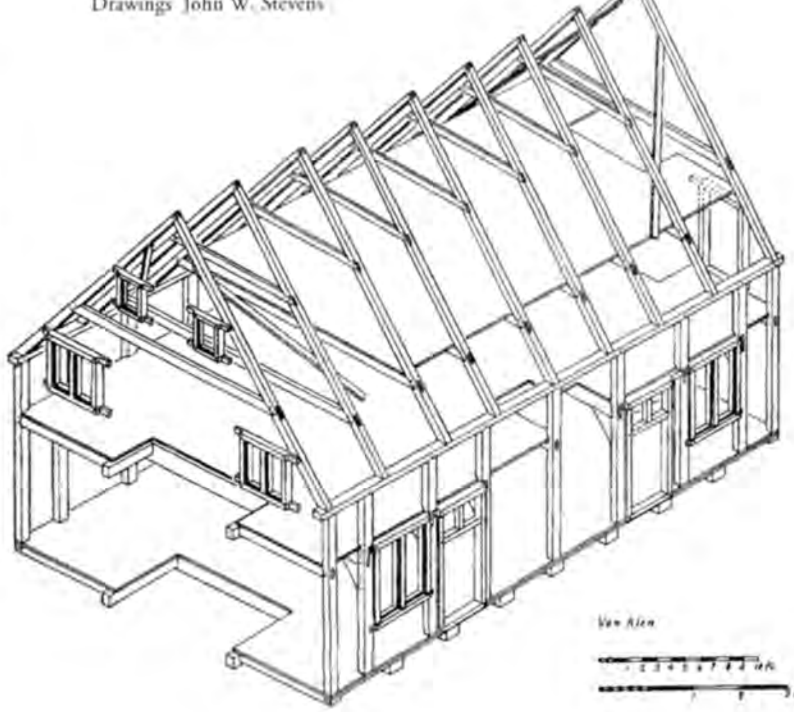


North elevation

At left, views of the Simeon Benjamin house, 1829, formerly at Northville, Suffolk County, New York, now at Old Bethpage Village, Nassau County. The exterior appearance of this house, built in an area of solidly British settlement on the north shore and east end of Long Island, gives no hint of the Dutch framing system within, and was revealed only by stripping for restoration.

Drawings John W. Stevens

At right, the Lucas van Alen house, 1737, at Kinderhook, Columbia County, New York. Isometric view of the timber frame from the southeast, with door and window framing shown in place. Front and rear walls are brick veneer. Three other examples exist, all built about the same time. (After Gerard Watland, with additional measurements by the author.)



A Trébuchet for Virginia Military Institute

IN the fall of 1995, Dr. Paul Chevedden, a visiting history professor at Virginia Military Institute (VMI), approached the engineering departments about his research into the trébuchet, a medieval siege machine capable of throwing large missiles long distances. Paul was exploring the idea of building a working replica of one of the machines. I became interested in the project and got copies of some archival drawings from Paul.

Among the drawings was a sketch of a one-man, traction-powered machine from the Spanish manuscript, "La Espana Del Siglo XIII," by Gonzalo Menendez Pidal. The machine was designed to help repel attackers while a larger machine was being constructed. Rocks of one to two lbs. could be thrown approximately 300 ft. to discourage attackers. Based on my limited time in the Army, I considered the one-man machine to be the modern equivalent of a squad mortar.

The construction shown in the drawings appeared to be within my abilities as a woodworker, and I became intrigued with the idea of building a replica. Sometime in October of 1995, I disappeared into my shop every evening for two weeks and produced a working replica. The maiden firing was on the VMI parade ground, firing tomatoes for students in the Civil Engineering Seminar class. The Dean of the Faculty appeared somewhere in the demonstration and was greeted with a barrage of water balloons.

The one-man machine also became a way to demonstrate applied physics to math, science and physics students. In November of 1995, I spent two days at The Collegiate School in Richmond teaching the equations of projectile motion to students. After laying out the basics, we would go outside and fire osage oranges across the soccer field. The students measured time and distance of flight using a stopwatch and surveying instruments. With that data in hand, we returned to the classroom and calculated that the projectile must have been traveling at about 150 ft. per second. The one-man machine has since been used to liven up Cub Scout meetings and as part of a medieval demonstration at a local therapeutic riding center for children with cancer.

The problem with modeling the small machine was that it only whetted my appetite for larger toys. Beyond personal interest, however, I hoped to get cadets at VMI (and Guild members) involved in producing a larger machine. In looking at the old drawings, I became convinced that construction of a larger trébuchet was just a different application of what I already knew about timber framing.

In teaching engineering, I find that there are entirely too few opportunities for students to do actual, hands-on work. Upon their graduation, we hope that our students are well schooled in theory, but it is up to the first job-site foreman to teach them the realities of construction. Perhaps a timber framing project would help speed up that process. And the level of expertise I had seen at Guild functions convinced me cadets could learn much from the skilled people in the Guild.

Beginning in the summer of 1996, I began planning (wishing for) a project to build a larger machine. Land clearing had just begun for a new water treatment plant being constructed behind our property. The local authority and the contractor agreed to donate some of the logs to the project. Stockpiling of logs began in September, and by the end of the clearing operation, there was a respectable pile of prospective trébuchet timbers in our back pasture.

MEANWHILE, I was trying to convince VMI that this was a worthwhile project. Every spring, the school holds a Field Training Exercise (FTX), a four-day period in April when classes are suspended and cadets participate in other activities. Cadets contracted with the federal armed services go off to their respective military obligations. Other cadets get involved in various community service projects, such as Habitat for Humanity house construction, community clean-up efforts and working in the local parks. The time frame seemed perfect for a Guild workshop, with the trébuchet as the project. Engineering cadets would have an opportunity for hands-on work, and history students could be involved in the Middle Ages in a very tangible way. And the idea was unusual enough to hook both groups. The VMI administration agreed to tolerate the idea.

The next step was to see if the Guild could be drawn in. I brought copies of sketches of the trébuchet to the Bethlehem conference, and began asking people if they thought it could be built. Ed Levin, graciously unconcerned by what he might be getting into, agreed that it seemed possible. Joel McCarty encouraged the idea, and millwright Jim Kricker, with his knowledge of wooden machinery, was approached for participation. Marcus Brandt acted like a child waiting for a new toy, but questioned the idea of a Quaker helping build a weapon. He seemed to accept the idea that the major purpose was to introduce a new group of people to the craft of timber framing.

After Bethlehem, preparations continued at a slow pace. A package of trébuchet reference material was sent to Ed, Joel and Andrea Warchaizer to begin the digestive process. Various departments at VMI agreed to contribute money to the project. More logs were collected. The Commandant of Cadets (Dean of Students at a normal school) was persuaded to release a group of cadets to participate in the project during the FTX.

Having gotten that go-ahead, recruitment of cadet volunteers began. I was particularly interested in finding a group of both engineering and history cadets who were interested in applying their learning to a real project. Also, I wanted to be certain that the cadets working on the project actually wanted to be involved (and weren't military style "volunteers"). The final group of 34 cadets was about 20 percent liberal artists and 80 percent engineers. As an aside, Andrea Warchaizer recruited three Norwich University cadets to join the throng.

PLANNING then ceased until an e-mail was received in early January from Joel McCarty stating that "it's not too early to begin planning for an April workshop." After that motion never stopped.

Basic decisions were made to handle the project as a VMI-run workshop simply because time was getting short. E-mail began flowing between VMI and various northeastern sites as we tried to estimate the time, materials and manpower to complete the trébuchet. Ed, Joel, and Jim Kricker graciously agreed to serve as instructors. Then, at Joel's suggestion, Donna Williams was asked to join the team. As VMI moves toward the first year of co-education, having the cadets taught by a very competent female engaged in a nontraditional role seemed a subtle way to open the cadets' eyes and minds. Donna, reinforced by the independent work of Andrea Warchaizer, Laura Brown, Paula Speirs and Janel Grice at the actual work-shop, made quite a favorable impression on the cadets.

With the help of Dr. Wayne Neel of VMI's Mechanical Engineering department, a set of basic dimensions and loadings for the trébuchet was developed. (See his accompanying article.) The design was also based on the idea that the machine would have to be easily disassembled and moved to Amherst in June. These thoughts were then sent to the instructors for comment and revision.

Ed Levin soon set to the working drawings. When he arrived at individual timber dimensions, log conversion began. Because of the limited project budget, the timber was produced with much manpower and little horsepower. The cadets got very direct lessons in applied leverage, inclined planes, and other simple machines as all of the timber was produced on a rented Woodmizer LT40 sawmill. Every Saturday in March was spent sawing and moving timber. The cadets were going to see this project go from raw logs to finished trébuchet. Watching them load the 36-in. diameter hemlock log that finally became two 8x18 uprights for the counterweight was quite a sight.

Also, in the process of producing the timber, the fellowship that marked the entire project began to develop. For lunch and dinner during each each sawing session Cindy Mullen and Joan Neel fed the hungry crew. (Cadets begged them for the secret salsa recipe.) Already, the stories were getting tall. Something about a trailer load of locust logs going sideways into an oak tree halfway down a mountainside at dusk. And then there was the cadet wood hardness tester who kept getting appendages between timbers and the ground. (He has survived the project and subsequent Treb firings intact.) A core group of about 12 cadets has been developing stories that they will be telling at class reunions for the next 50 years.

The last timber was sawed and delivered to the site Thursday evening before Guild members started arriving on Friday. The cadets spent Friday setting up camp and getting ready for the work to come. All of the participants were to camp at the project site for the duration. I knew from past Guild functions that there was as much to be learned from discussions after hours as during the actual work. The camping was to allow the opportunity for that learning to take place.

The mix of military cadets and free-spirited Guild members promised to be interesting. At lunch Saturday, Cindy Mullen hit on the perfect vehicle to get the two groups to mix. She required each cadet to have a Guild buddy in tow before she would let them through the chow line. From then on friendships started to build, stories were generated, and entire group began to gel. Early on a cadet approached me to report, "Donna Williams knows what she's doing, and she knows how to teach!" The project was off to a fine start.

For the next four days (and a half when things got behind schedule) 40 Guild members and 35 cadets worked their hearts out to produce the first historically accurate trébuchet seen in the last 500 years. The Guild members took cadets in hand and taught them the intricacies of square rule layout, proper use of the hand tools, and then assembly and the final fitting of the joints. Throughout, the cadets were impressed with the framers' willingness to share their craft, and their patience in teaching the uninitiated. Even as assembly continued under firetruck lights at 12:30 Tuesday night (Wednesday morning) patience, teaching and safety remained the watch words of the effort.

IN time, Marcus Brandt won the respect of the cadets. As he led the raising crew, Marcus would send the cadets out to pick up rocks whenever there was a lull, either for the counterweight, or for actual ammunition, the cadets were never sure. They just learned to stay busy. However, as rigging was put in place to raise the main arm using only manpower, it became obvious to the cadets that Marcus knew his craft. Marcus also finally admitted that cadets knew how to work when properly instructed. As a result of his efforts, Marcus is now known across the VMI post as "Marcus the Mad Quaker."

Finally on Wednesday morning, the machine was complete and ready to fire. The first shot was a bit of a surprise, and a dud. (See Janice Wormington's report on page 15.) However, adjustments were made and about 2:00 that afternoon the first successful shot was fired. Pandemonium broke out on the hilltop! Framers and cadets slapped backs, hugged, jumped up and down, and screamed like banshees. Something approaching the equivalent of three years' work had come to a successful conclusion with only one minor, last-minute hitch. (But, then, the last professional trébuchet slingmaker died 500 years ago.) Much was learned by the cadets and the framers. New friends were made, tempers never flared, and nobody got hurt!

Because of the half-day delay in finishing, a number of Guild members had to leave before seeing the trébuchet fire. For the next several days, the telephone and e-mail lines lit up with questions: "How did it go?" "Did it really work?" "How heavy was the rock and how far did it go?" Physical separation from Lexington didn't seem to diminish interest in the outcome.

As the project got underway, word seeped out to the Lexington community. With the successful firing on Wednesday, and the subsequent news coverage, calls streamed in asking when we were to fire the trébuchet again. The decision was made to hold an open firing day for the community. On Friday, April 18, shots were launched hourly from 2:00 to 7:00. A steady stream of people came out to watch, ranging from a 5-year-old who watched every shot, to members of a local retirement community who watched from their van.

Then the calls began to come in from the local schools. The third grades had been studying medieval times and wanted to see the machine. The eighth-grade science and physics classes had just finished levers, and wanted to see the mechanics of the machine. On Friday, April 25, a series of firings were held for local school students. More than 400 students asked questions, watched, and wondered. The day was a great success.

This is where the real worth of the project begins to come out. There is no practical reason to build a replica of a 500-year-old weapon. But as a mechanism to teach any number of things, it has become a wonderful tool. The original intention was to give cadets some hands on experience with engineering, history and construction. That desire was fulfilled beyond all expectations during the workshop. Guild members gave cadets a precious gift by sharing their skills and knowledge with them. With the confidence that could have only come from actually helping build the machine, the cadets were able to explain the project to members of the local community and school students. It was very satisfying to watch a cadet lead a class of third graders around the trébuchet, describing the workings of the machine as he went. Even better were the wide eyes of the third graders when the pin was pulled.

The future of the trébuchet after Amherst is a bit murky. The original planning didn't extend far beyond the first shot. However, we hope to continue to use it as a teaching tool. With some coordination, it could be taken around the state and set up as a demonstration for school students. The cadets have asked to form a timber framing club so they can maintain the trébuchet and develop and construct similar projects. Already mentioned are bridges for the Appalachian Trail, a storage building for the trébuchet or a workshop to house further projects.

THANKS go out to all the Guild members who came and shared their craft. The project would never have been finished without your hard work. The VMI administration was mightily impressed with your skills and dedication. The cadets learned that there is much to be learned from watching those who know what they are doing and are proud of what they do. And the Lexington community learned about a wonderful group of craftspeople. Thank you all for your efforts!

Joel McCarty had originally hoped for a field commission. Joel should be reminded to be careful what to wish for as wishes can come true. VMI has already extended the invitation for the Guild to return in April of 1998. Without even knowing what the project may be, the administration is confident that whatever General McCarty and his troops are involved in will be worthwhile. —GRIGG MULLEN II

Lt. Col. Mullen teaches Civil Engineering at the Virginia Military Institute at Lexington.

Building the Lexington Bellifortis

ONE way of measuring the vigor of a historic carpentry tradition is the brevity of documentation required to describe a timber frame. The principle goes something like this: the better established the building tradition, the fewer the words and scantier the drawings needed. Contracts for the construction of first-period American houses and layout boards for classical Japanese buildings reflect this rule in their spare description and elemental iconography. It seems that when the craft is thriving, knowledge of it runs broad and deep among both builders and owners, making detailed documentation superfluous. Trébuchet design offers an object lesson in this principle. Like other forms of medieval construction, the lines of the trébuchet were governed by rules of geometric proportion so profound that by knowing the dimensions of any one piece, one could infer the size and shape of the entire machine.

But while the geometry that governs the form of the trébuchet is amply documented in medieval manuscripts, little comes down to us about the joinery used to lock its parts together. Surviving drawings seem to indicate a preference for notched and lapped joints over blind mortises, but these drawings were executed by artists and illustrators rather than professional builders and are naïve and picturesque, often embodying Escheresque internal contradictions. So the first authentic timber trébuchet in four or five centuries features joinery more speculative than traditional. Likewise our nomenclature, since original trébuchet part names also did not survive the passage of time.

The new machine was to be a smaller scale replica of a siege engine known as the Innsbruck Bellifortis, documented in 1405 by Conrad Kyeser in his portfolio of the same name. If you believe that the modern era holds the patent on impressive war machinery, consider first our Lexington Bellifortis with overall dimensions of 19x20x33 ft., 6 in. featuring a 23-ft., 6-in. throwing arm, 2 ft. in diameter, pivoting 16 ft. off the ground, driven by a 4-ft. deep, 9-ft. radius quadrant counterweight basket holding 10 tons of ballast, the whole apparatus weighing in at close to 15 tons.Then contemplate its medieval predecessor with a 60-ft. throwing arm 6 ft. in diameter, powered by a counterweight in excess of 50 tons, and capable of tossing a 1-ton projectile some 200-300 yards. As historian Barbara Tuchman observes in her 1978 work *A Distant Mirror,* "For belligerent purposes, the 14th Century, like the 20th, commanded a technology more sophisticated than the mental and moral capacity that guided its use."

Will Beemer

Above, Treb is winched down from at-rest (vertical position) and readied for firing below. The sling is draped at the nose of the throwing arm and then fed between the sleepers, where ammunition is placed in the pouch. See back cover for photo of pouch discharging at correct angle for arm and sling.

Other than scale, the principal difference between our machine and its namesake was the canted superstructure of the new trébuchet: the sides of the Lexington Bellifortis were tilted inward 6 degrees off the vertical, decreasing main axle span from 8 ft. to 4 ft., 6 in., thereby greatly reducing axle bending stress from 5,000 psi at full length down to 2,800 psi in the shorter span. This number still exceeds NDS working values, but might be reasonably considered for a military application, especially when the piece in question was cut from perfect black locust whose dry wood modulus of rupture approaches 20,000 psi.

Considering the prospect of repeated assembly and disassembly, the through tenon with outside wedge was the joint of choice. Pegged, blind tenons were used where through joints were not practical. The rectangular base of the trébuchet was formed of a grid of timbers in two layers, a lower stratum of three sleepers overlaid by two sills. The end sleepers (8x12x10) were through-tenoned and wedged to the sills (8x9x20) which in turn were wedged into half-dovetail notches in the central main sleeper (10x12x20). For stability on rough ground, the sleepers were relieved on their undersides by Dave Dauerty's mighty hewing axe.

The equilateral triangle superstructure was formed on each side from 8x8x16 struts rising from sill to main upright, the latter built up of a 10x8x16 central post sistered to 8x8 side pieces with wedged 2x6 splines. The triangles were braced and tied together with horizontal 8x8s. Once again all tenons were through-wedged save for the ends of the struts and the inner ends of the ties, which were pinned.

The open main bearing for the throwing arm was worked into the top central portion of the built-up upright. The 9x9 main axle and 8x8 counterweight axle were mortised and wedged into the arm, which tapers from 24 in. at the butt down to 12 in. at the tip over 22 ft., 8 in., with an additional 10-in. snout (reduced to 8-in. diameter) to hold the free end of the sling, releasing it at the top of the swing to discharge the load. Journals for the windlass used to cock the machine were cut half into the upper surface of opposing struts, half into bearing blocks with tapered upper surfaces, with the two parts clamped together with iron bands. The windlass must be located as high as possible to insure clearance for the loaded sling when firing, but not so high as to interfere with the swinging basket or put its arms out of reach of the crew.

A windlass axle center 3 ft., 4 in. off the ground accommodated these conflicting requirements, bringing the windlass arms to a 5 ft.-8 in. elevation at the top of their swing. Since we could not be sure about the travel path of sling and ammo (which varies with ballast and projectile weight), we removed the windlass before firing, replacing it with a taught string. After several firings, the joint evidence of video cameras and broken strings made a convincing case for spinning the superstructure 180 degrees to put the windlass on the target side of the machine, out of harm's way. This requires the addition of a block to redirect the windlass line but, as it turned out, auxiliary tackle is needed in any case to arm the fully ballasted trébuchet .

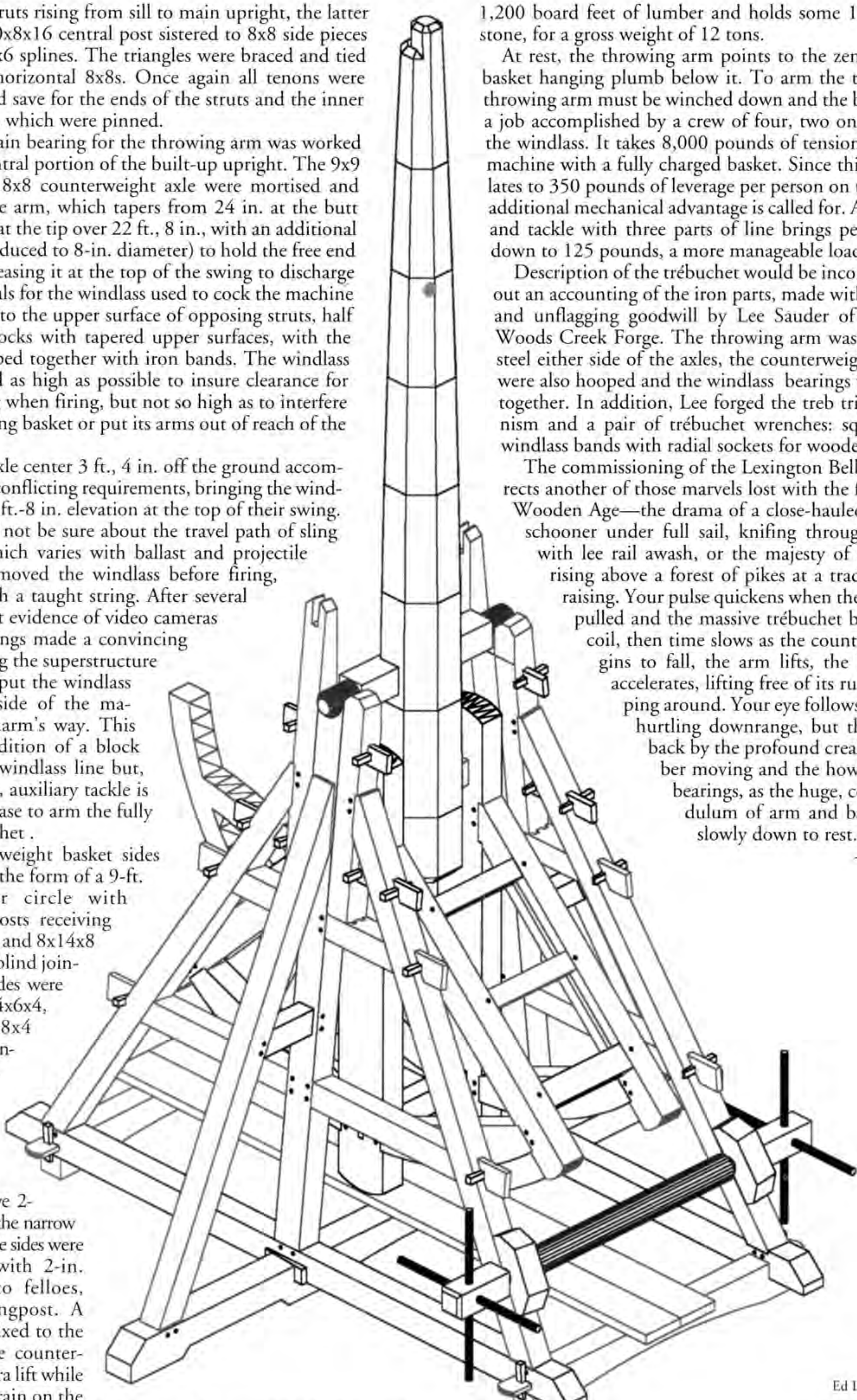
The counterweight basket sides were framed in the form of a 9-ft. radius quarter circle with 8x18x14 kingposts receiving 8x10x10 spokes and 8x14x8 felloes, with all blind joinery. The two sides were connected by 4x6x4, 6x6x4 and 6x8x4 girts, also blind-tenoned and pinned. Three-in.planks tacked to the felloes formed the basket floor. The spokes were grooved to receive 2-in. plank sealing the narrow ends, and the wide sides were also sheathed with 2-in. plank nailed to felloes, spokes and kingpost. A curved prop affixed to the basket gives the counterweight some extra lift while also reducing strain on the throwing arm in the cocked position. The assembled basket used 1,200 board feet of lumber and holds some 160 cu. ft. of stone, for a gross weight of 12 tons.

At rest, the throwing arm points to the zenith with the basket hanging plumb below it. To arm the trébuchet, its throwing arm must be winched down and the basket raised, a job accomplished by a crew of four, two on each end of the windlass. It takes 8,000 pounds of tension to cock the machine with a fully charged basket. Since this load translates to 350 pounds of leverage per person on the windlass, additional mechanical advantage is called for. Adding block and tackle with three parts of line brings per-capita pull down to 125 pounds, a more manageable load.

Description of the trébuchet would be incomplete without an accounting of the iron parts, made with speed, skill and unflagging goodwill by Lee Sauder of Lexington's Woods Creek Forge. The throwing arm was ringed with steel either side of the axles, the counterweight kingposts were also hooped and the windlass bearings were banded together. In addition, Lee forged the treb trigger mechanism and a pair of trébuchet wrenches: square slip-on windlass bands with radial sockets for wooden spokes.

The commissioning of the Lexington Bellifortis resurrects another of those marvels lost with the fading of the Wooden Age—the drama of a close-hauled Gloucester schooner under full sail, knifing through the water with lee rail awash, or the majesty of a huge bent rising above a forest of pikes at a traditional barn raising. Your pulse quickens when the firing pin is pulled and the massive trébuchet begins to uncoil, then time slows as the counterweight begins to fall, the arm lifts, the loaded sling accelerates, lifting free of its runway, whipping around. Your eye follows the boulder hurtling downrange, but then is called back by the profound creak of big timber moving and the howl of wooden bearings, as the huge, complex pendulum of arm and basket dances slowly down to rest.

—Ed Levin



Ed Levin

Design Considerations for a Large Trébuchet

ON a windy Virginia hillside in Rockbridge County, a solitary sentinel stands watch over the rolling countryside and the Blue Ridge Mountains along the far horizon. With its throwing arm at rest towering 33 ft., 6 in. off the ground, this great wooden machine bears witness to the frenzy of activity that placed it here only weeks earlier.

During their Spring '97 Field Training Exercises, some 35 cadets from the Virginia Military Institute and three visiting cadets from Norwich University (Vermont) built and erected this medieval siege weapon under the careful tutelage of members of the Timber Framers Guild. This magnificent piece of machinery did not just appear as a gift from the Hale-Bopp comet (which could be clearly seen to the west). It was the result of numerous months of design work and countless hours of planning, coordination and hard labor.

Following Greek and Roman traditions, the medieval mind thought in terms of geometric forms. Experience with wood and iron were combined with these familiar geometric proportions to produce machines and mechanical devices.

Starting with the medieval sources, principally drawings, and armed with a set of dividers, we sought relationships that would be reasonably consistent among the various pictorial sources. The measurements thus derived, along with intuition and engineering judgement (educated guesses), produced a viable design. We verified the validity of the proportions by calculating bending and shear stresses of the beam and axles for a machine of wood.

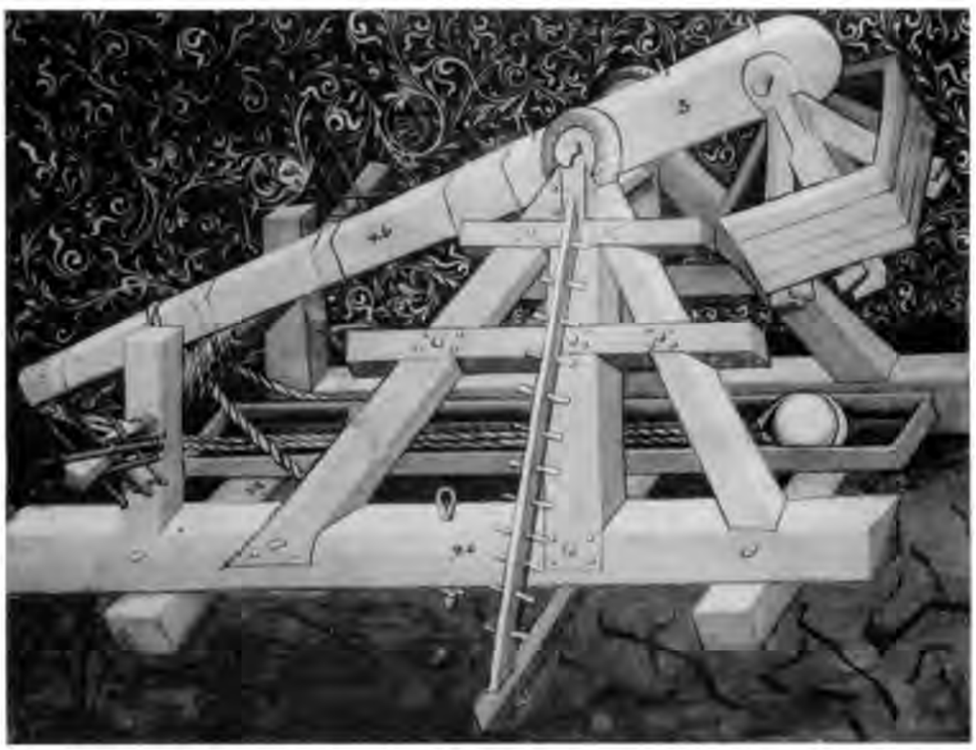
The best resources were drawings from the *Innsbruck Bellifortis* by Conrad Kyeser von Eichstätt (1405), and from an Arabic work entitled *The Elegant Book of Trebuchets* (1463), understandable to VMI history professor Paul Chevedden. The *Elegant Book* was not available to us until after this design was complete. However, its drawings confirmed many of the design considerations we had taken into account from the Innsbruck Bellifortis and information distilled from many other medieval drawings and sketches.

MAIN BEAM. The main beam, or throwing arm, should be at least 10 times longer than its diameter, which should be at least 20 in. The ratio of the main beam of the VMI trébuchet, as built, was 12.8 to 1 (23 ft., 6 in., or 282 in., to 22 in.).

For smaller machines this proportion would go up, since the diameter is scaled down to the 4/3 power, to maintain equivalent stress. The resulting, rather stiff, beam would cause the attached sling to do most of the work of throwing the projectile.

Various tapers of the main beam may be used. Historically, beams reflected the natural taper of trees or were purposely tapered to shift the center of gravity toward the larger end of the beam (butt end). The taper exploits the principle of the lever to increase the speed of the tip of the beam, when opposed by a slow, large mass at the butt end, yet maintains the center of gravity close to the center of rotation. It was found that when these two centers were close together, the beam was easier to rotate; today we would say that the rotational inertia is kept low. If the butt diameter is taken as unity, the tip diameter in the European tradition seems two-thirds or one-half, while in the *Elegant Book* the ratio is one-third.

Some main beams appear to be made up of several pieces scarfed and laminated, held together with Dutch pins and bound with rope coils, as in the case of the Innsbruck Bellifortis, or with iron bands.



The Göttingen Bellifortis. Length of throwing arm section of beam, 43 ft., 8 in. Distance between main axle and counterweight axle, 7 ft., 6 in. Length of main axle (i.e., distance between uprights), 21 ft., 6 in. Length of base, 42 ft., 11 in.

The small end of the beam is formed into a horn or prong. In length, this prong should be one-half the diameter of the butt end of the beam, and in diameter from two-thirds to one-half the diameter of the small end of the beam. The prong may be set in the center of the small end of the beam or along the top edge. The *Elegant Book* shows a horn offset along the top edge, in length two-thirds the diameter of the butt end (which is also three-quarters of the diameter at the axle) and in diameter one-half the diameter of the small end. The prong is smaller than the beam so that the loop at the end of the sling will not slip down the beam. The center of gravity of the tapered beam is determined by placing a small-diameter log under it and finding the point of balance. For the location of the main axle, European trébuchet makers appear to have arrived at a distance of approximately one-third of the way from this point to the butt end of the arm. In the *Elegant Book*, by contrast, an iron ring counterweight was added to the butt of the beam to move the location of the center of gravity toward that end, and the axle was then placed at the center of gravity of the beam, thus obtaining an acceptable trhowing arm length. Several European pictures show this feature.

LENGTH RATIOS. The length from the base of the horn to the rotational axle will be referred to as the length of the throwing arm, and the length from the rotational axle to the counterweight axle will be referred to as the counterweight arm. The latter distance was determined by measuring the length of the throwing arm and dividing by an appropriate factor. This factor seems to be a function of the purpose of the machine. A factor of three would be used to throw large projectiles for short distances, increasing to six when smaller projectiles were used, resulting in larger distances. The typical machine seems to have used five. The *Elegant Book* uses this value exclusively. The Innsbruck Bellifortis gives six in terms of the numbers shown on the drawing, which are also mentioned in the text, although the accompanying drawing shows a ratio of 5.2 to 1 between throwing arm and counterweight arm.

The main beam is finished off by banding on either side of the two axles and evenly spaced bands along the beam. These bands may be of iron or, as is the case in many medieval drawings, the beam may be wrapped with rope along its length or intermittently banded.

AXLES. There are two axles in the trébuchet, the main axle on which the main beam pivots and the counterweight axle from which the counterweight is suspended and rotates when the throwing arm is released.

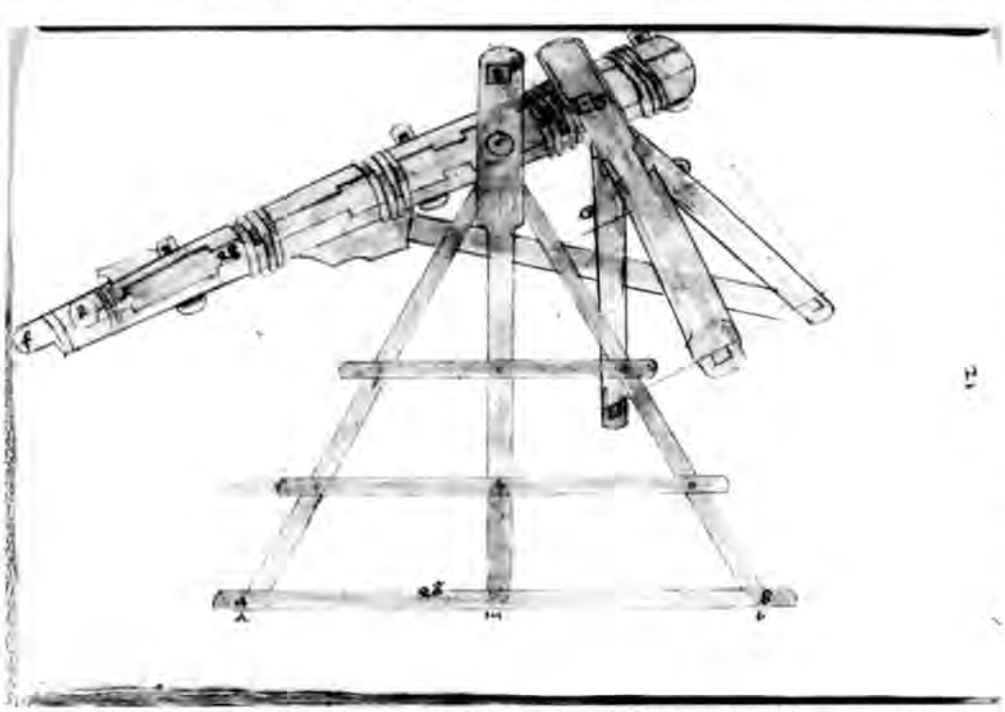
The overall length of the main axle is one-half the length of the throwing arm. Little evidence exists that the axle was shorter than this, although our modern reasoning and common sense argue that a shorter axle is stronger. The diameter of the axle is one-third to two-fifths of the diameter of the main beam at the journal bearing. (In the VMI treb, this diameter became the breadth of a square hole through the main beam.) The axle is located on the centerline of the main beam, or, for the largest machines, displaced one-tenth of a diameter downward. In moving the axle down, more wood remains at the top of the beam to help withstand the bending stresses at this point. The Innsbruck Bellifortis text mentions the offset, but the approximate value is derived from the drawing. The axle should be constructed from a tough, high-strength wood. (The VMI axle was made of locust and displaced about one-twentieth of a diameter—an inch—below centerline.)

The counterweight axle should be about the same diameter as the main axle, but no smaller than two-thirds. According to drawings of the Innsbruck Bellifortis, this axle should be round through the main beam and square through the counterweight supports. Most medieval drawings depict the entire length of the counterweight axle as round.

The counterweight axle on the VMI trébuchet is square through the main beam and round through the counterweight supports, as is the main axle. This design was preferable since cutting a round hole of large depth by hand would almost certainly create journal bearing interference problems through the main beam. The length of this axle is approximately one-quarter of the length of the throwing arm.

Both of these axles must be carefully mortised into the main beam perpendicular to the centerline. If the trestles that support the main axle are angled inward, the main axle becomes shorter and the counterweight must be carefully dimensioned to clear them during operation. In order to permit a shorter axle to reduce flexing, the VMI design has a 6-degree inward tilt of the trestles.

A mixture of water and lard was used to lubricate the wood-to-wood bearings of the main and counterweight axles. Other lubricants such as soap could be used instead.



The Innsbruck Bellifortis, base length 44 ft., 10 in. The MS reads: "If you want to shoot at close range, make the rope connected to the throwing arm shorter and the other attached to the pouch [shorter as well]; this is the way to adjust for distance (near or far)."

COUNTERWEIGHT. The profile of the counterweight is one-quarter of a circle having a radius of three times the length of the counterweight arm. The *Elegant Book* gives a value of approximately twice this length, yielding a smaller basket, and having a width equal to the length of the counterweight arm. The counterweight basket is sided with boards to a height established by at least half the radius measured along an edge. The boards were typically nailed on. The container would have been filled with heavy material, often rock, sand or earth.

The shape of the counterweight results in a large moment of inertia, such that it does not rotate easily as it falls.

The Innsbruck Bellifortis drawing shows the axle through the counterweight supports to be moved slightly (one-tenth of the support width) toward the main axle, shifting the counterweight back slightly. Apparently this was again to relieve stress on the back edge of the counterweight supports when a prop was used in a ready-to-fire position.

SUPPORTING FRAME. The supporting frame consists of two trestles, both equilateral triangles. The sides of these triangles are equal to the length of the throwing arm. The main axle is placed exactly at the apex of the trestles.

The *Elegant Book* gives both the height of the trestles and the length of the base as equal to the length of the throwing arm. This results in an isosceles triangle and gives a higher trestle than the equilateral triangle design (although in another Arabic text the equilateral triangle is used). The trestles are placed parallel to each other, separated by a distance equal to one-half the length of the throwing arm, and constructed principally of square beams approximately two-thirds the size of the main axle, with the main vertical the same size as the axle at the bottom and twice to three times the size at the top where the axle goes through. All depths are two-thirds the diameter of the main axle.

A sleeper, in length equal to that of the throwing arm, is placed across the middle of the base. Buttresses, side props, are mortised into the sleeper, angling up to meet the tops of the trestles and the vertical supports for the axle of the main beam. Sleepers are set at the front and back to complete the base.

PROP. A curved prop is fixed to the back side of the counterweight near its bottom edge. This prop engages the main beam when horizontal and remains engaged as the arm is drawn down and the counterweight raised to its firing position. When the trébuchet is fired, the throwing arm ascends and the prop remains engaged until the main beam is approximately 30 degrees below the horizontal. At this point the counterweight falls downward and away. While the prop is engaged, the counterweight acts as a fixed counterweight with an extended moment arm.

If a prop is not used, the counterweight falls away from the main beam almost immediately. The use of the prop was thought to increase the available potential energy, thus contributing more energy to the projectile. Scale models suggest that this is not the case. Whether the prop is used or not, the projectile travels approximately the same distance. Where does the extra energy go?

The current thought is that the increased energy goes into rotating the counterweight back to a vertical position, so that little of the energy is contributed to the projectile.

Why did medieval engineers feel the need for this device? I suggest that the prop allows the use of a smaller main beam by reducing the stress above the main axle for the final stage of readying the trébuchet for firing and in the initial dynamic loading upon firing. A moment is applied about the main axle instead of just the counterweight load at the butt end of the main beam.

By propping the counterweight out initially, a larger (5:3) moment arm is produced, which decreases to a smaller (5:1) moment arm when the throwing arm disengages from the top of the prop. The prop, when used in the medieval drawings, engages the main beam approximately the same distance in front of the main axle as the counterweight arm length behind the main axle.

WINDLASS. A windlass is used to bring the throwing arm down into the firing position. If the windlass is rear-mounted, it should be placed along the back side of the supporting frames at a height equal to the length of the counterweight arm, or it will interfere with the rope of the sling as the projectile is pulled out from under the windless. This problem may be avoided entirely if the windlass is forward-mounted, with a roll bar or blocks used to the rear of the base to engage the arm for drawing down. The diameter of the windlass should be at least the diameter of the main axle and should ideally incorporate ratchets on both sides to hold the great strain of the counterweight basket as the arm is drawn down. For the moment, the VMI trébuchet uses only a rope break.

The rope used to haul down the throwing arm passes over the arm at a point where a wooden prong is attached. The position of this prong is four-fifths of the throwing arm length from the main axle and on the top of the beam. The two ends of the rope that pass over the throwing arm are wound individually around the windlass for simultaneous operation. The wooden prong is indicated on the Innsbruck Bellifortis drawing and is what is used on the small-scale model. In the *Elegant Book*, a prong is also used, except that it is made of iron and called a "finger." In some of the medieval sources, and on the VMI trébuchet, an iron band is mounted around the throwing arm with a ring attached to the bottom. The rope passes through this attached ring.

Before the trébuchet is ready to fire, the ropes attached to the windlass must be slackened and each rope hung on its respective side near the main axle. This may be accomplished by wooden pegs or metal hooks, or by looping around the tops of the vertical supports of the axle.

PROJECTILE TROUGH. Before firing, the projectile is placed on planks resting across the sleepers of the base, extending from the front of the trébuchet to the back of the machine, parallel to the throwing arm. The length of this trough is equal to that of the throwing arm. The planks may have short vertical sides. Sides are not necessary although they were the usual case in the Middle Ages.

FIRING MECHANISM. The firing mechanism used on the model and on the VMI trébuchet consists of three rings. One ring, in the plane of the beam, is fixed to the end of the throwing arm by an iron band. The other two rings are joined, tied or welded together, then chained or roped back to a sleeper such that the throwing arm, in the ready position, is at a 45-degree or greater angle with the horizontal.

The firing pin, a small iron bar with an eye, is put through these three rings, with the two rings on either side of the middle ring attached to the beam. The firing pin is attached to a rope and removed by pulling to initiate firing. Considerable force must be expended to extract this pin. The pin may removed by striking with a hammer. However, this method is not considered safe as the person striking the pin would have to move immediately to safety. A pull arranged from a safely remote location is preferable.

SLING ASSEMBLY. The sling assembly is constructed of two ropes adjoined to a sling. One rope is attached to the end of the throwing arm and the other is looped over the prong at the end of the throwing arm. The size of this loop can affect the frictional force that must be overcome in order that the loop release at the optimum time to cast the projectile.

The sling attached between these two lengths of rope consists of rope netting tied like a hammock, narrowing toward each end. The length of the netting should be twice as long as the width. The width is determined by taking two-thirds of the circumference of the largest projectile that is to be fired.

The length from the throwing arm to the bottom of the sling can best be gauged if the main beam is in a horizontal position, when the sling should just touch the ground. For heavier projectiles it may be as long as to the back edge of the trestle at ground level. This results in a sling length of between 87% and 100% of the length of the throwing arm.

The short text that accompanies the Innsbruck Bellifortis drawing says to make the sling length less than the length of the throwing arm. Experience with smaller scale models indicates that longer lengths, 110 to 120 percent of the throwing arm length, work well for heavy projectiles.

To achieve a maximum range, the sling should release when the throwing arm is vertical or slightly past vertical, since at this point the counterweight will have contributed all the energy that it can to the projectile, and when the sling itself has reached a 46.4-degree angle above the horizontal. For a given sling length, increasing the weight of the projectile above optimum will give a lower angle (with respect to the horizontal) and therefore a higher trajectory and a shorter range. Decreasing the weight of the projectile will give a higher angle (with respect to horizontal), a flatter trajectory and, again, a shorter range.

Care must be taken not to increase the weight of the projectile such that the angle of release goes to zero with respect to the horizontal, since this will send the projectile straight up—and then back down onto the trébuchet and any persons standing in its immediate vicinity. Increasing the weight of the projectile past this point will result in the projectile being cast backward.

PROJECTILE. When the projectile has been placed in the sling in preparation for firing, the tension in the sling should be made as great as possible. The projectile should be approximately spherical to reduce air resistance and to decrease wear on the sling. The weight of the projectile should be between 100 to 200 times smaller than the counterweight, typically closer to the 100 value for first trials. For the first shots, I suggested using a low counterweight value, but picked a stone that I considered optimum for the chosen sling length of 16 ft. The ratio was about 133:1. At this writing, the range of the shots has been from 165 to 225 yards, measured horizontally from the middle of the trestle, with projectile weights of 95 to 60 lbs.

OTHER CONSIDERATIONS. The design elements detailed here are only one aspect of building such a device. This experiment would not have been possible without the expert knowledge of Ed Levin, who reviewed this design and planned the joinery, Jim Kricker's amazing knowledge of timber, cutting large members and joinery, Wes Quinlan's and Tom Miller's able assistance in producing the main throwing arm, Joel McCarty's and Donna Williams's leadership—and the devoted skill of all the other members of the Timber Framers Guild who gave so much of their time, knowledge and love of their craft. —W. Wayne Neel

Col. Neel, Ph.D. and PE, teaches mechanical engineering at the Virginia Military Institute and provided much of the new Treb design.

How I Spent My Spring Vacation

WE set out early Friday morning, enthusiastic and hopeful, for our five-day camping and trébuchet-building adventure in the Virginia mountains. The car is packed with camping gear (borrowed), hand tools and power tools (just in case) and warm-weather clothes (just in case). The sun is shining, a good omen, I figure. There has been no mid-winter trip south this year, and we in western Massachusetts want to forget the cruel April Fool's Day joke of a 2-ft. snowfall.

Our trip from the Berkshires will take about ten hours, through mostly pretty countryside. (But there is really no good excuse for northern Pennsylvania, around Scranton and Wilkes-Barre—it's a sorry gateway to the Appalachians.) Nearing Virginia, I grab the guidebook to read aloud the description of the historic battlefields and natural wonders we're whizzing by. Brian's as much of a tourist as I am a camper. He tolerates my recitation as a better alternative to actually visiting the sites. (Or reading the highway signs, which my mother still does to fill the silence. Brian fears this might be a genetic thing.) The purpose of a trip, in his mind, is to get where you're going. No unnecessary stops, say, for lunch or bathrooms. Fortunately, cars do need fuel eventually.

We exit I-81 at Lexington, check the map, and spot a Guild sign at the entrance to McKethan Park. Grazing cows lead me to wonder what kind of park we will find. It's almost 6:00, and we join a motley group of timber framers and one handsomely uniformed person who turns out to be Col. Wayne Neel, professor of mechanical engineering at VMI. We fit right in with the motleys. At the shelter, we all wait for something, or someone, to organize us. Meanwhile, a lot farther down the hill, another encampment grows, as several hundred Boy Scouts gather for a weekend rendezvous. (Nothing to do with ours.) A steady stream of cars going by much too fast kicks up dust. We neglect to roll up the window. Within days, we will become as grungy as the car.

The shelter at VMI's McKethan Park is the center of action for the next four or five days: where we eat, where we work, where we congregate around the fireplaces to keep warm and where we wait in line to use the cold-water toilets. This is Virginia, in April. It's not supposed to dip into the 30s at night. Eventually it will dip into the 30s during the *day*.

Since the park also serves as cow pasture, our first challenge is avoiding the cow pies liberally dotting the landscape. The VMI cadets are already encamped in the grassy lot; we pitch our tent in the wooded area next to the shelter. The camping gear is borrowed, and I'm anxious to set up before dark. We had test assembled it only once in our living room the day before. Brian predicts this will be our last camping experience. What we do know is that it's our first. I still have an open mind, though it's crowded with childhood memories of leaking tents, pesky mosquitoes and inedible food. But this is the '90s. Surely things have improved.

Throughout the evening, other Guild members and their families straggle in, arriving from even greater distances: Calgary, Alberta; Wixom, Michigan; Jackson, New Hampshire; Luling, Louisiana; Grapevine, Texas. More people, more activity, and the cavalry (in the form of Joan Neel, Cindy Mullen and Paula Speirs) arrive, with snacks, trays of food and marinated chicken for the grill. When cadets man the grills to cook for us, I know this will be an unusual weekend.

Off in the darkness, we see the glow of a computer screen, as Ed Levin sits in his van working to finish the drawings, a comfortable and unprecedented eight hours in advance of the start of cutting at 7 the next morning. (A certain amount of design work took place on the drive down from Vermont, with Ken Rower on the left, intermittently studying drawings placed over the steering wheel, and complaining, and Ed on the right, entering changes on his laptop computer powered by the lighter socket.) Ed now joins us and reports, "Only four more to do." We all gather around the drawings to observe and consider our task for the coming days. I feel the energy and excitement grow. Cases of a bottled beverage arrive at the shelter. Talk continues late into the night.

We retire to our tent. The ground is hard, the night is cool, the sleeping bag confining and the traffic noise from I-81 impressive. Otherwise, camping is all I thought it could be. Brian is asleep in a minute. I'm not. I listen to the cows and carpenters trade moos and howls.

SATURDAY. We crawl from our tents, greeted by the warm sunshine and the sound of Wayne Neel's bagpipes at 7 AM. There are only two bathrooms so we wait our turn. It could be much worse, couldn't it? It could be an outhouse or a latrine. I do wonder where are the hot showers promised in the advance material, but it's too early for me to wonder much. (The hot showers turn out to be under the VMI gym three miles away.)

A figure swathed in an aluminized space blanket drifts down from the hill from which our Treb will eventually test-fire. It's Ed in search of toothpaste. Too tired to erect his tent, he slept under the stars with the cows to keep him company.

After chowing down a hearty breakfast served by the VMI mess, we are called to action by Joel McCarty (who wishes to be field-commissioned *General* Joel McCarty). Cindy Mullen gives us name tags, although it isn't all that hard to tell framers from cadets—something to do with hair length and attire. We learn that many of the cadets haven't heard their first names in several years and may not react at first to hearing anything but "Mister." Col. Mullen also reminds us that cadets won't do anything unless they're told to, but that they will follow orders.

Ed presents his drawings and describes what the Guild instructors and volunteers will build (he hopes). The superstructure consists of two triangular side-frames on a broad base, supported by large timber braces; the other critical pieces are the arm, axles, basket and windlass. There will be work stations as usual, with small groups of experienced framers and cadets working together on the various sections of the trébuchet. I don't understand how the various pieces will all work together until Col. Neel arrives with a wooden scale model he built; it's one-sixth the size of the planned machine. A long arm is mounted in a frame and pivots around an axle placed about one-fifth of the way along the length. At the short end of the arm is a basket for the counterweight, and at the long, tapered end a long rope sling is attached to carry a projectile of some sort. At rest, the arm stands more than 33 scale ft. tall. When the long end of the arm is drawn down, the counterweight basket rises. When the arm is released, the basket falls and the long end of the arm accelerates upward, the sling coming along behind it even faster; one end of the sling eventually slips off and the projectile flies forward. At least that's the theory.

To demonstrate, as the group stands at a respectful distance, Wayne loads the sling with a small rock, cocks the arm, pulls the firing pin and . . . *Voila!* The rock flies. It works!

Now all we have to do is build a bigger version—a much bigger version (18 ft. tall on the frame and weighing many tons). The plan is to use only hand tools, to respect history, to make communication easier among instructors and cadets and to minimize the possibility of injuries. Under the watchful eye of Guild instructors and expe-

"Like this, I say...." quoth Ed Levin.

Janice Wormington

Col. Neel piping, Col. Mullen moving out on the double.

rienced timber framers, the VMI cadets observe, learn, and eventually do.

Among the active timber framers are Donna Williams (Carlisle, Pa.), Janel Grice (Grapevine), Paula Speirs (Wooster, Ohio), Laura Brown (Norwell, Mass.) and Andrea Warchaizer (Alstead, N.H.), who all direct the cadets. The cadets' experience working closely with these instructors is good practice for the next school year, we learn, when VMI accepts the first female cadets. VMI has a historic rivalry with The Citadel in Carolina, and the Virginia institution hopes to do a better job of accepting women within its ranks. That shouldn't be too hard—for VMI to win this match, all the VMI male cadets have to do is avoid setting the female cadets on fire.

All the timber to be used is local (most logs were donated), and the locust for the vital axle was felled and sawn out by Grigg Mullen and the cadets. Manhandled with levers by the young arms and backs of the VMI cadets, a 26-ft. hemlock log arrives in the open field, raw material for the trébuchet's long arm. The conversion will be chiefly the job of New York millwright Jim Kricker. Since the trunk is far from straight, he must find its two central axes and carve out a tapered arm for the machine. With assistance from Wes Quinlan, Tom Miller and Ed Levin, and a crew of cadets to execute the many details, this job will take two days.

MEANWHILE, back at the shelter, everyone is focused on layout and cutting of the supporting joinery, some fifty pieces in all. And there are axle-ends to be formed carefully from the square, and 7-in.-dia. holes to be bored in through 8-in.-thick bearing pieces. General McCarty has sternly warned that mistake-makers will be used as ballast in the trébuchet's counterweight basket . . .

By afternoon, the physical work begins. Cadets learn the proper operation of the boring machine, used to rough out the mortises, and they compete to be the fastest. Timber framers generously loan their precious chisels, saws, and other hand tools, but hover nearby like anxious nursemaids, lest the edges are ruined. The floor is, after all, concrete. A few tools do suffer in the process, but the damage isn't irreparable.

That night, we watch a slide show presented by Paul Chevedden. Paul, a medievalist who knows Arabic (in which there is trébuchet literature), is visiting professor at VMI's Department of History and Politics and a leading authority on the machine. We learn the trébuchet originated in China in about the fifth century B.C., and a thousand years or more passed before it appeared, via the Middle East, in Europe. Paul notes that the trébuchet had a longer history of use than any other war weapon, including ballistic cannon; its dominance as a war machine on the medieval battlefield was unchallenged because of its efficiency, durability, portability and stability. We also learn a trébuchet is not a catapult, which uses tension to fling objects. Rather, a trébuchet uses gravity and a counterweight (or traction) for its power.

The trébuchet is also seemingly unrivaled in popularity for the thriving group of historians, fans, and certifiable nuts around the world who build replicas of medieval siege machines. There is the story of an engineer who built and rode his catapult—straight into the Blanco River. (I think it had something to do with working too long in the hot Texas sun.) There are other stories, of the pair (a dentist and a sculptor) who aspire to build a Texas-sized catapult to the tune of $50,000, or of the wealthy British landowner who dreams of an American theme park featuring car-throwing Trebs—and, finally, of the Florida neigh-

Will Beemer incognito demoing the Millers Falls boring machine.

You just can't keep that man Dauerty away from the hewing axe.

bors who practice throwing bowling balls from their backyard, narrowly missing passing vehicles. (At least the Guild's and VMI's motives are pure. I think.)

Perhaps the Treb's popularity is partly due to having appeared on TV in *Northern Exposure* and in the film *Monty Python and the Holy Grail.* Whatever the reasons, Welshman Michael Barnes of TV's PBS series *Nova* is sure to keep the interest alive. He's filming the activities as part of his research for a future PBS film devoted solely to this machine. We chat about other PBS shows he's been involved with, from raising huge obelisks as the ancient Egyptians did, to experimenting with how the Romans could have constructed a roof over the Coliseum.

SUNDAY. After a chilly night in the 30s, and the morning again with the bagpipes at 7 AM, I'm reminded why I detest all alarm clocks and clock radios. It's overcast, and we hope it won't rain, as the shelter is the only cover. We chow down another VMI breakfast, same as yesterday but with gravy on different things. No cholesterol concerns here.

Work continues on the trébuchet arm, and the noise level increases in the open field, as Jim Kricker chainsaws the trébuchet arm and Mike Goldberg trims the axle shoulders. Back at the shelter, the cutting, the mortising, the chiseling continue. The intensity and work pace also increase, as our maximum leader General McCarty emphasizes the need to show real progress today.

I notice the cadets who have a natural talent and feeling for the wood they're working, and those who prefer the brute force method. One carefully smoothes a tenon, noting, "Perfection takes time." I reassure a few that if their engineering careers don't work out, they'll always have a job as a carpenter or a handyman. This isn't what they want to hear. I learn that cadets are not assured of a commission after their four years, and that for many, their first year may be the toughest enduring the Rat Line (a way to maintain discipline by the upperclassmen).

More Guild members and their families arrive, and a family atmosphere prevails amid all the activity. Supervised by the moms in shifts, kids of various ages find ways to entertain themselves, one with a homemade bow and arrow, others swimming in the river nearby. A few dogs wander in, nose down vacuum-cleaner style, in search of dropped morsels. They find mostly chips from the battalion of boring machines.

MONDAY. 7 AM, reveille, or whatever the Scottish equivalent is called. Those bagpipes *again.* Yesterday was a long day, as Gen. McCarty kept pushing back when meals were served, taking malicious advantage of the change to Daylight Savings Time. At least the sun is out again, though the wind chills the air. It's just as well, since we proceed from urgency to panic. Will we be ready on time to assemble the machine and launch a boulder on Tuesday? Joel says, in response, "We all must work harder."

The trébuchet's arm emerges, along with the notch at the tapered end to hold the sling, thanks to the efforts of Jim, Wes and Tom. Lexington's blacksmith, Lee Sauder, arrives in the afternoon to measure the arm for its octagonal iron bands, which must be individually sized to match the taper of the arm. Meanwhile, architect and rock-climber Keith Speirs and Andy Smith, a VMI sophomore, are handed two lengths of rope, two reference books on knots and the assignment to make a macramé net to hold a boulder as it is launched. It must keep the boulder secure while the sling is pulled out swiftly from beneath the machine and swung in an upward arc, then release the boulder at a certain point along the arc. Except for

A pause in the night work Tuesday with the Treb almost ready to go.

Will Beemer

The first firing, sling doesn't release, boulder swings wildly.

the overall proportions supplied by Col. Neel, there are no rules of thumb or common knowledge about trébuchet nets, so they must make it up as they go. After a couple of false starts, they arrive at a plan to make a continuous net, using two knots that won't slip when a hundred-pound rock nestles inside. They hope.

Up to this point, there's been a marvelous quiet—the absence of machine noise—in and around the shelter, as only hand tools have been used. It's been easy to talk and call out to other people. But no more; we're running out of time: the power tools appear.

Colin Stotts (the Calgary speed demon) takes a chain mortiser to the basket arms, Laura Brown fires up the worm-drive to cut boards to face the basket and tool wizard Dave Crocco (Ridgewood, N.J.) brings out of his notorious van a huge, powered, industrial-strength boring machine to drill out, among other things, the giant square axle holes, some 2 ft. through, in the trébuchet arm.

Certain quiet procedures continue. A VMI cadet smoothes 7-in. dia. axle ends as other cadets turn the spokes for the windlass on Grigg Mullen's lathe. Work continues till after dark, as we await burgers and hot dogs cooking on the grill. We huddle around the shelter's two fireplaces, braving smoke pouring out of them from powerful downdrafts rushing over the roof of the shelter, and regretting we didn't pack hats and mittens (some people did, actually, and had no regrets). Following dinner, and attracting an audience of framers and cadets with clearly nothing better to do, Jim Kricker continues working on the arm, with portable lights to assist.

TUESDAY. Assembly is beginning on the top of the hill above the shelter. Our Treb will shoot from above, just as those in medieval times were often mounted high on the castle walls. Standing on top looking down on the fields, I can imagine raining shots upon an advancing army. (I have to imagine it, as the Boy Scouts wisely left Sunday morning.) There is great anticipation, and not a little worry. Will it work? That is the question to be answered soon.

No army can work on an empty stomach, and two of the heroes of the weekend assure that doesn't happen: Cindy Mullen and Joan Neel work with the VMI mess to feed us three times a day, tend the fireplaces when the temperatures dip, retrieve the bathroom key when the door jams (locking its victim inside) and do all the other invisible and thankless tasks necessary for a project of this size.

At the top of the hill, a dump truck discharges the ballast rocks for the counterweight basket. Curtis Milton remarks that the basket looks like the peace symbol, and ponders that irony. A New Hampshireman rom Jackson, he also notes that in his state, the words "ax" and "axle" are pronounced the same. Knowing that in my own Massachusetts there is Conservation of Rs (they disappear from "pahk" and "cah" but reappear in "idear" and "Budder"—that's Buddha to the rest of the world), I ask Curtis where in New Hampshire the LEs reappear. Curtis says he's still wondering.

The Treb's 18-ft. side-frames go up with the help of ropes and gin poles, under the supervision of Marcus Brandt, who commences work at the site by raising his own Revolutionary War flag. We now begin to appreciate the size of the machine and the damage it could inflict, whether on a castle wall or on an advancing army or a group of unskilled practitioners. Its size demands respect and careful planning by people who know what they're doing. From Paul Chevedden's slide show we recall the lesson of the 16th-century Spanish explorer Cortès. The rock his trébuchet launched flew straight up, and then fell straight down, crushing the trébuchet to bits. Napoleon III's first performance wasn't much better, for his trébuchet managed to throw things backward.

On one long brace Andrea Warchaizer has neatly chip-carved the Guild's TFG logo and on the other, under her supervision, a visiting cadet from Norwich University (Vermont) has carved the VMI logo. The wetting bush, the traditional bough affixed to the top of any new timber frame in northern cultures, appears at the top. However, we are all still too busy to "wet."

The arm, complete with neatly fitted metal straps, arrives at the top of the hill. A meeting is called with Ed Levin, Joel McCarty, Marcus Brandt, Jim Kricker and others to discuss exactly how the massive arm, now measuring 23 ft., 6 in. long, will be raised. The details worked out, ropes and rigging hoist the arm into position. Fifteen-year-old Grigg Mullen III operates the windlass. As day turns into night, a fire truck arrives to supply much-needed light. Work continues till midnight, in preparation for the Big Event.

WEDNESDAY. Dawn. The massive trébuchet awaits. Stones gradually fill the lower part of the counterweight basket as the cadets quietly pass them, one by one, along a human chain between the rockpile and the Treb. The arm is drawn down and cocked by heavy work on the windlass, a modestly heavy boulder is nestled into the sling stretched out under the machine and Cols. Neel and Mullen and Grigg Mullen the younger prepare for firing.

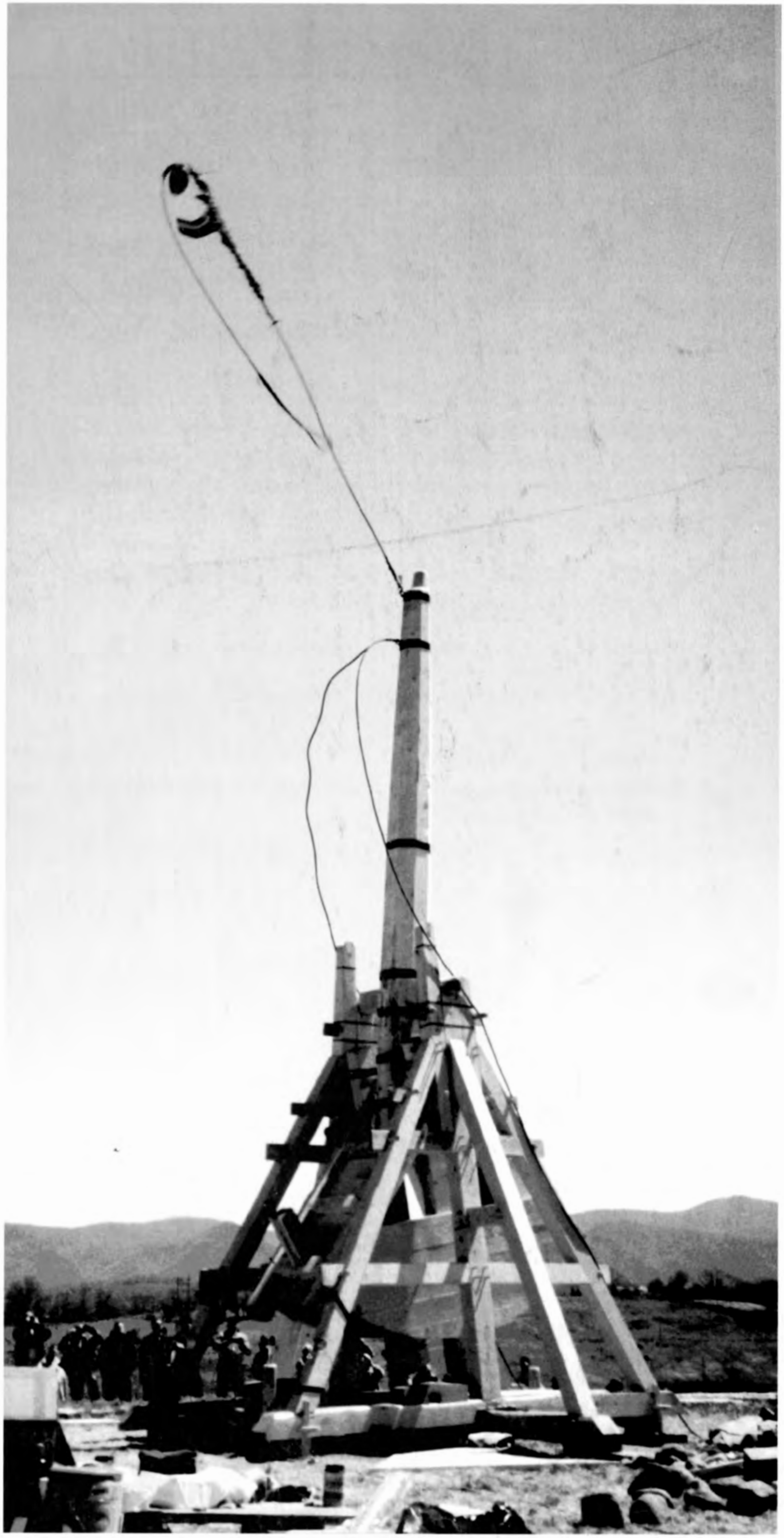
When the pin is pulled, the mighty arm swings up and forward, groaning wildly in its wooden bearings, the sling whips forward and then—the sling whips back around in a circle! The boulder, still trapped in the net, crashes against the arm, which is now swinging heavily to and fro, groaning like a huge wounded animal. As the sling continues to swing around the arm, cadets and framers rush for cover, but there is no real danger. Under centrifugal force, the stone has lodged firmly inside the netting, which had closed around its charge like a purse-string.

When things quiet down, Grigg rescues the stone. It's back to the weavers to revise the sling. They change the knotting to prevent the net from closing around the stone, and, to make doubly sure, add a modern touch, a cardboard liner. The machine prepared once more, the firing pin is pulled and the wooden bearings and other moving parts again shriek and moan ("an intrinsic and vital part of the trébuchet experience," Ed Levin notes). A roar from the crowd. It works! Eventually, on the third successful launch, a 95-pound boulder flies 700 ft. down the hill, according to unofficial cadet measurements along the ground. The cadets boost Grigg Mullen for a victory march. We are all elated and relieved at once. No one is injured and the Treb fires straight and true. We say our good-byes and go. It isn't until I get home that I finally realize why people camp. It's to appreciate a bed, a hot shower and a bathroom with no lines.

—JANICE WORMINGTON

Janice Wormington with husband Brian manages the Guild's web page (tfguild.org). Her account of the Lexington workshop was augmented by details supplied by Ken Rower.

Port Orford Cedar, Curry County, Oregon



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The Lexington Bellifortis, caught by Will Beemer's camera just after releasing a boulder from its sling. The arm has just gone past plumb and the sling has risen somewhat past 45 degrees to the horizontal. Firing direction is to the right in this photograph.